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The Urban Heat Island effect in London's residential stock: Energy consumption and risk of overheating.

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Abstract

Considering the adaptive comfort approach, this article estimates if interior conditions in London's naturally ventilated residential stock are comfortable under the Urban Heat Island (UHI) effect and predicts if climate change will lead to overheating. How the UHI affects energy consumption is also estimated. The most average household profiles in London have been modelled and simulated. Suitable weather files have been used to estimate energy consumption and interior comfort conditions. Future conditions have been estimated using climate change predictions based in UKCP09. Results show that the UHI is currently saving energy in London and interior conditions remain comfortable for the average households. Future climate change estimations show that occupants will adapt to changing conditions and that archetypes' resilience can avoid overheating until 2080 only relying in natural ventilation. Critical occupation patterns prone to overheating have also been simulated.

Keywords: Urban Heat Island, Adaptive Thermal Comfort, Energy efficiency, Overheating, Climate Change

1 Introduction

The Urban Heat Island (UHI) is the common denomination given to a local change in the climate of urban landscapes. Its main characteristic is that the centres of urban areas are normally significantly warmer than the surrounding countryside. The UHI is considered a hazardous and costly event to be avoided. According to on-going research and current policies, higher temperatures in the city centres cause overheating and serious comfort and health problems in the population which lead to higher mortality rates (WHO, 2008; GLA, 2006). Besides, higher temperatures in the city centre also cause higher energy consumption in buildings because air conditioning demand is always proportionally higher than the potential savings in heating energy (Kolokotroni et al, 2006).

However, the UHI is a permanent change in the local climate and according to the adaptive comfort approach people can successfully adapt to their permanent local conditions in free-running buildings (Humphreys, 1978). Temporary and acute temperature changes like heat or cold waves move temperature out of this adaptive comfortable range and could affect population's health. However, heat waves are not caused by the UHI. Besides, many buildings in London – many of them residential – are not equipped with air conditioning and therefore, the UHI might also be saving energy in winter.

Even if present conditions might be comfortable, due to global warming future higher temperatures might not make possible for buildings in London to keep comfortable levels in their interior spaces without air conditioning.

2 Objectives

1. Appraisal of the most common naturally ventilated households in London to verify if interior conditions can be currently kept within comfortable levels.

2. Estimation of the potential energy savings caused by the UHI effect at present.

3. UKCIP09 climate change projections for the UK have been used in the same models to predict if in the future homes will be at risk of overheating and if the energy performance in buildings affected by the UHI will change following global warming.

3 Methodology

The typologies, thermal characteristics and occupancy patterns are consistent in every present and future scenario to keep results in comparable levels.

Three archetypes and two occupancy patterns have been defined. Data from the latest Census (ONS, 2011) define the two most common households in London: a 2-bedroom flat occupied by two people and a 3-bedroom terraced house occupied by three people. The standard characteristics of these buildings have been adopted from the baseline typologies developed by Zero Carbon Hub in the Task Group recommendations to define zero carbon homes (2009). These typologies are not particularly thermally inefficient, but considering that simulations will be run until 2080, these standards will be more realistic for future scenarios. The two most common archetypes are mid-terraced house and mid-flat. However, recent studies about UHI and overheating in the residential sector concluded that homes – particularly flats - are more affected by exposure within the building than location within the UHI (Mavrogianni et al, 2012). Following these results, the flat archetype has been simulated in mid and top location within the building. Two different occupancy patterns have been developed: the first one – average occupancy – assumes that occupants work or study following usual working hours and therefore, the typologies are not occupied during the central hours of the day. The second pattern – continuous occupancy – considers profiles more vulnerable to overheating like working from home or elderly people, and assumes that every thermal zone defined in the archetypes is continuously occupied with at least one person. Further details on these data selection including heat loads, services, building construction and simplifications can be found elsewhere (Lafuente, 2013).

These typologies and occupancy patterns have been modelled using EnergyPlus building simulation software. Simulations for present scenarios have used weather files from two datasets: three locations - Uxbridge, British Museum and Cavell Street - were provided from the 1999/2000 Survey of London's UHI (Watkins et al, 2002) and other four locations – Islington, Heathrow, St Albans and Welwyn – are available from the Prometheus Project (University of Exter, 2011). This last dataset is based in the output of UKCP09 and also provides probabilistic climate change projections in the same four locations for future scenarios: 2030, 2050 and 2080.

Yearly simulations have been run in EnergyPlus to obtain energy consumption per square meter for each typology in the different locations and occupancy patterns. Estimations of the relative energy performance or each of them have been calculated from these results. EnergyPlus output also provides hourly interior and comfort temperature records according to BS EN 15251 (BSI, 2007), which follows the adaptive comfort approach. To predict overheating, the three criteria defined by the TM52 (CIBSE, 2013) – also based in the adaptive comfort approach – have been verified in the locations most affected by the UHI (central London) under both occupancy patterns.

4 Results

4.1 Present

4.1.1 Energy consumption

From the seven available locations, St Albans is the least affected by the UHI, so it has been used as the baseline for energy consumption calculations. Figures 1 (Mid Flat) and 2 (Top Flat) display the relative annual energy consumption of each location for both occupancy patterns compared with St Albans. The percentages are calculated dividing the annual energy consumption per square meter of each location by the energy consumption in St Albans. The results obtained for the mid-terraced house and the mid-flat are very similar. Detailed results and graphs can be consulted elsewhere (Lafuente, 2013).

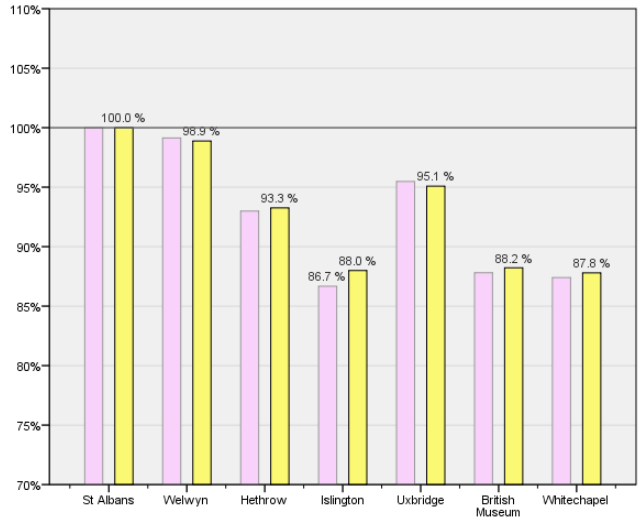

Figure 1. Mid-Flat relative annual energy consumption of each available location compared with St Albans.

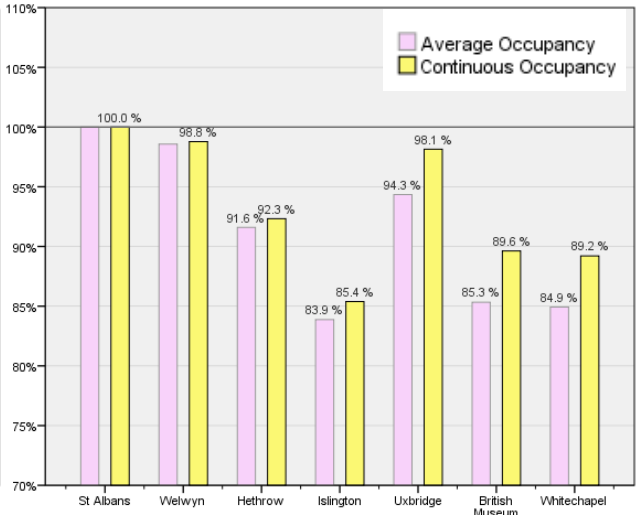

Figure 2. Top-Flat relative annual energy consumption of each available location compared with St Albans.

Mid Flats in central London are currently using around 13% less energy than the same typology in St Albans. Top flats use between 10 and 16% less energy depending on the occupancy pattern.

4.1.1 Risk of overheating

According to TM52 (CIBSE, 2013), a space will not suffer from overheating if it complies with any two of the three criteria defined in the publication. Table 1 shows compliance in every zone in central London:

Table 1. Comfort compliance at present according to TM52 in central locations.

	BRITISH MUSEUM 1999/2000 (Watkins et al, 2002)												**CAVELL ST.** 1999/2000 (Watkins et al, 2002)												**ISLINGTON** 1961/1990 (University of Exter, 2011)											
	Mid Terrace				**Mid Flat**				**Top Flat**				**Mid Terrace**				**Mid Flat**				**Top Flat**				**Mid Terrace**				**Mid Flat**				**Top Flat**			
	Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.	
	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B
CRITERION 1	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.7%	0.7%	0.0%	0.0%	0.9%	0.9%	0.0%	0.0%	0.1%	0.2%	0.1%	0.0%	1.1%	1.1%	0.0%	0.0%	0.9%	0.9%	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.8%	0.8%	0.0%	0.0%	1.1%	1.1%
CRITERION 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRITERION 3	-1.4	-1.4	0.8	1.0	0.3	-1.7	0.5	-1.6	0.4	-1.8	0.9	-1.6	-1.2	-1.4	0.9	1.0	0.4	-1.8	0.6	-1.1	0.4	-1.9	0.8	-1.6	-1.2	-1.2	1.3	1.2	0.2	-1.1	1.2	-0.6	0.4	-1.5	1.9	-0.3

Compliance with TM52 | Not compliance with TM52 | N/A Calculation not necessary

4.2 Future

Islington is the only location in central London with available weather data to quantify the future effect of the UHI and climate change in energy consumption and comfort levels. Calculations are based in two climatic scenarios: average prediction (50th percentile probability and medium level emissions) and worst case scenario (90th percentile probability and high emissions scenario).

4.2.1 Scenario 1: Medium emissions levels - 50th percentile probability

4.2.1.1 Energy Consumption

The graphs in this section show relative results compared with different baselines to analyse the future evolution of the relative annual energy consumptions due to the UHI, climate change and the combination of both. The red column displays the effect of climate change only: It compares the present and future energy consumption estimations of the archetypes located in Islington with the energy consumption of Islington at present. The yellow column displays the evolution in time of the relative energy consumption due to the UHI only. It compares present and future results from simulations in Islington with the results of simulations located in St Albans in the same year. The orange column shows the effect of the combination of UHI and climate change together. It compares present and future results obtained in Islington with present results in St Albans. Finally, the grey column also displays the evolution of the combination of climate change and UHI together compared with Uxbridge results, because much relevant literature about London's UHI uses Uxbridge as the baseline location for their calculations (Watkins et al, 2002; Kolokotroni et al, 2008 & 2009; Oikonomou et al, 2012).

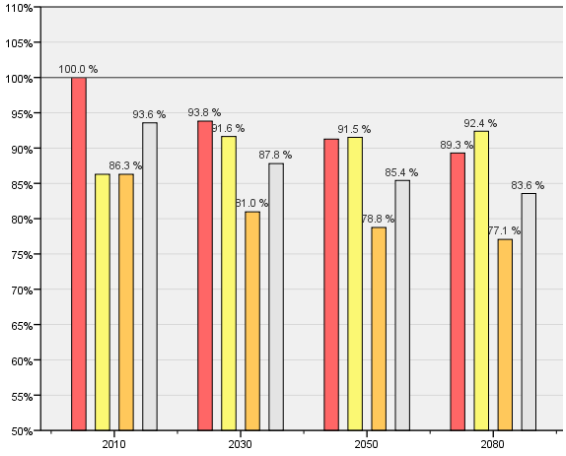

Figure 3. Terraced House – Average Occupancy. Relative annual energy consumption. Medium emissions scenario

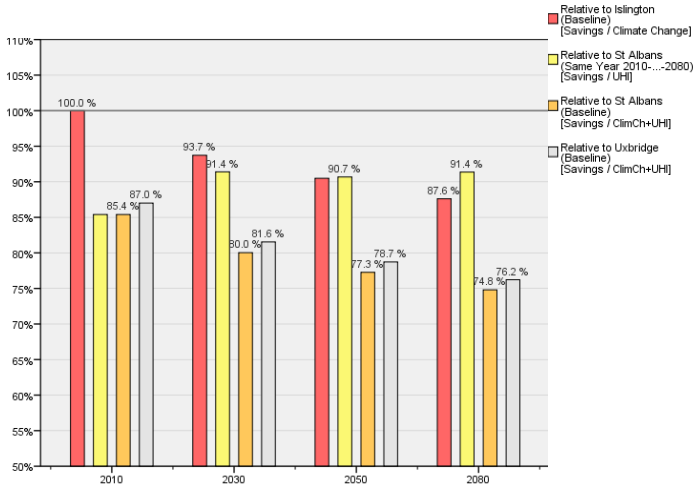

Figure 4. Top Flat – Continuous Occupancy. Relative annual energy consumption. Medium emissions scenario

Figures 3 and 4 show two tendencies. Firstly, climate change progressively reduces the relative energy consumption in all the archetypes because the heating period in winter is shorter and the rest of the loads remain constant. Relative energy reductions due to climate change reach 10-15% in all typologies. The effect of the UHI in the energy consumption of buildings follows the opposite pattern. However, this does not mean that the UHI intensity will decrease. This pattern is caused by the reduction of the relative importance of the heating loads compared with the rest of the energy loads. The combination of both UHI and climate change effects show that the effect of climate change will have a much higher influence in relative energy consumption patterns than the UHI. Again, results between the terraced house and mid flat are very similar. Complete results for all typologies and occupancy patterns can be found elsewhere (Lafuente, 2013).

4.2.1.2 Comfort

Table 3 shows the energy comfort compliance according to TM52 criteria for Islington at present, 2030, 2050 and 2080. Results show that in the medium emissions scenario, all baseline archetypes are resilient to climate change and will succeed keeping interior conditions within comfortable levels. Occupants will adapt to new permanent climatic conditions.

Table 2. Future comfort compliance in Islington according to TM52 in central locations – Medium emissions

ISLINGTON DSY - MEDIUM EMISSIONS - 50th percentile																																
	2030												2050												2080							
	Mid Terrace				Mid Flat				Top Flat				Mid Terrace				Mid Flat				Top Flat				Mid Terrace				Mid Flat			
	Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.		Average Occ		Contin. Occ.	
	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Zone 1A	Zone 1B	Z1 GF	Z2 1F	Z1 GF	Z2 1F	Zone 1A	Zone 1B	Zone 1A	Zone 1B
CRITERION 1	0.0%	0.0%	0.3%	0.4%	0.1%	0.1%	1.3%	1.4%	0.1%	0.1%	2.1%	2.2%	0.1%	0.0%	1.2%	1.0%	0.2%	0.1%	2.2%	2.2%	0.2%	0.1%	1.6%	0.0%	0.0%	0.1%	0.4%	0.3%	0.1%	0.1%	1.4%	1.4%
CRITERION 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRITERION 3	-0.1	-0.5	0.6	1.0	1.0	-0.8	1.5	-0.8	0.4	-1.6	2.0	-0.3	1.0	0.8	1.7	1.6	0.9	-0.5	1.1	-0.4	1.5	0.0	2.0	0.2	0.7	1.0	1.1	1.3	1.2	-0.7	1.7	-0.6

5 Conclusions

Interior conditions in London's residential stock can currently be kept within comfortable levels in every location and UHI intensities. The properties with weaker thermal performance than the baseline defined in this article could be retrofitted to this standard using a limited amount of currently available strategies.

Depending on the occupancy pattern, the UHI effect is currently saving up to 10-15% energy in the naturally ventilated residential stock.

The residential stock might start to suffer overheating after 2050 in a high emissions scenario. The energy savings caused by the UHI effect will also be significantly reduced in the future – but the UHI will not disappear. Even though the mitigation of the UHI might not define a major concern for the residential stock at present, it should probably be mitigated in the future depending on the evolution of the CO_2 emissions.

Global warming will have dramatic consequences in London's residential stock: By 2080 every home in London might suffer from overheating in a high emissions scenario.

6 Acknowledgements

Weather files from different locations in London's UHI recorded by Watkins et al (2002) were kindly provided by Prof Maria Kolokotroni from Brunel University.

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